

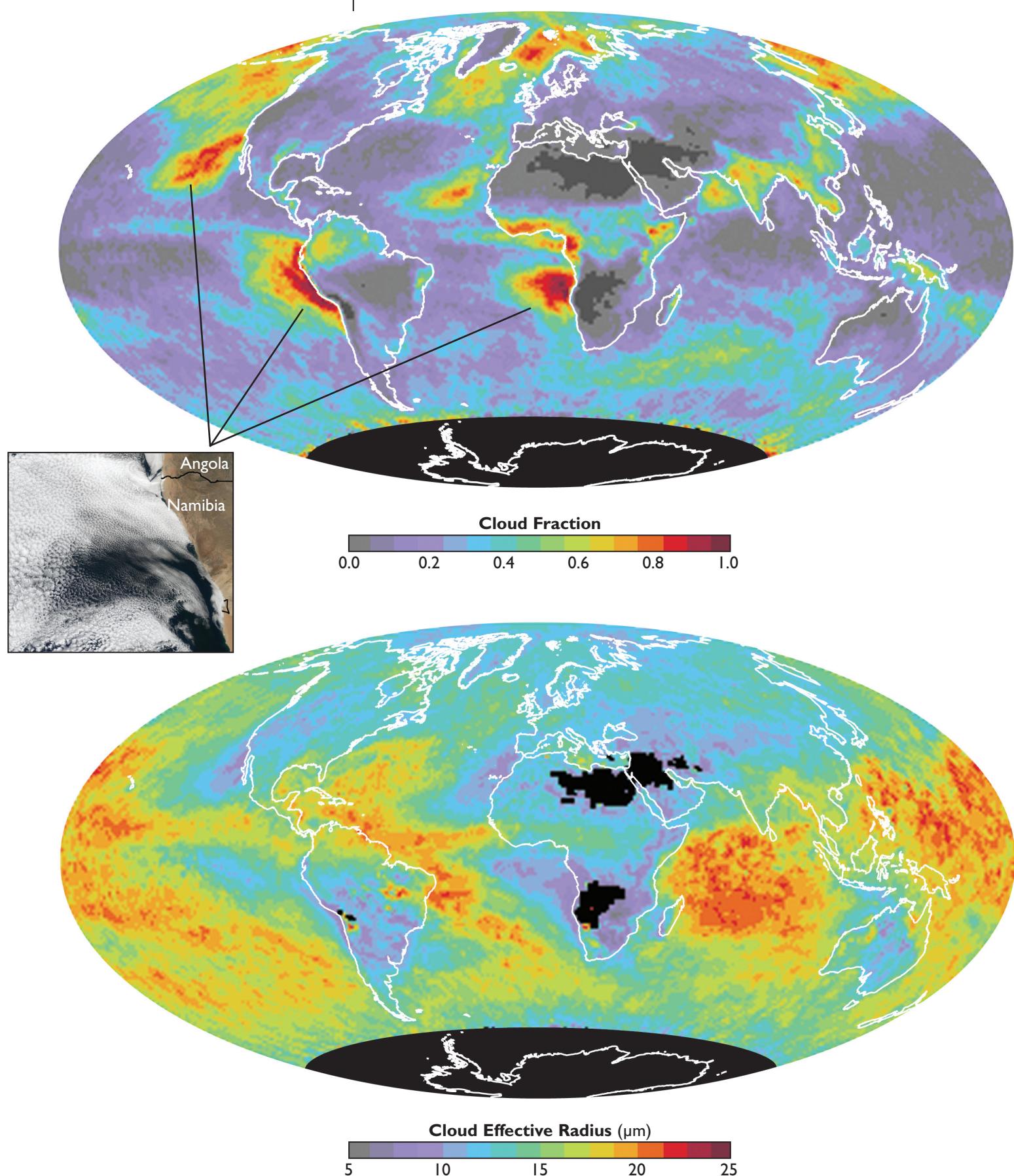
# Cloud Optical and Microphysical Properties

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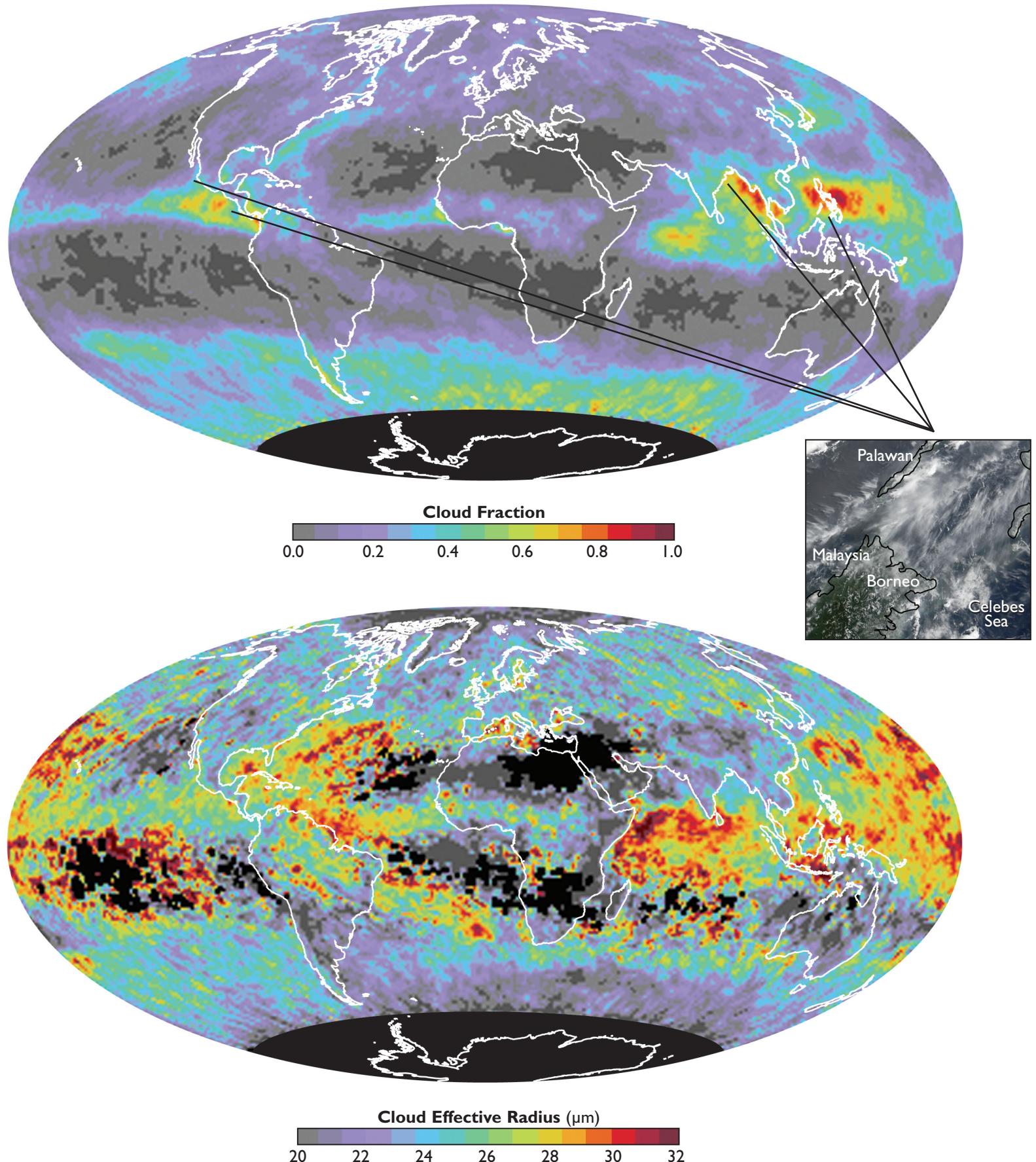


Clouds occur in the Earth's atmosphere in both liquid water and ice phases. John Aitken, a Scottish physicist who did research on atmospheric dust and the formation of dew, cyclones, and evaporation, first reported in 1880 that "when water vapor condenses in the atmosphere, it always does so on some solid nucleus; that the dust particles in the air form the nuclei on which it condenses; and if there was no dust in the air there would be no fogs, no clouds, no mists, and probably no rain." Atmospheric dust is today referred to as cloud condensation nuclei, and they are ever present in the Earth's atmosphere as a result of breaking waves, dust storms, atmospheric chemical transformation in urban and industrial areas, and smoke from natural and manmade fires. But what kind of clouds does the Earth have today? This can

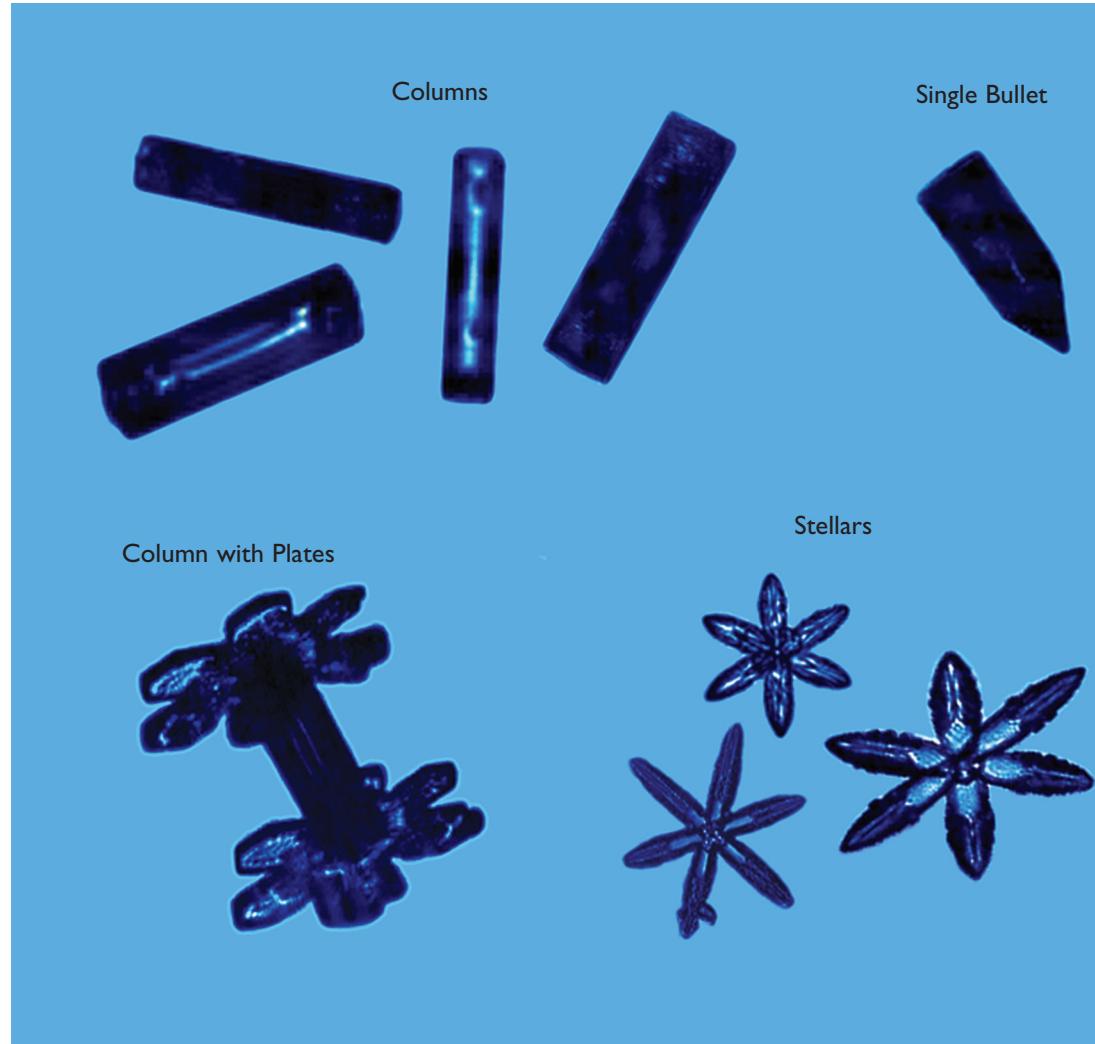
Deep convective cumulonimbus capillatus incus cloud composed of upper layer ice crystals in the anvil overlying lower-level cumulus congestus clouds composed of liquid water droplets. (Photograph taken from the NASA ER-2 aircraft by pilot Jim Barrilleaux over Florida on July 19, 2002.)



Global distribution of cloud fraction (top) and cloud effective radius (bottom) of liquid water clouds for July 2006. (Data from the MODIS instrument on the Terra satellite.) Inset: Marine stratocumulus clouds off Angola and Namibia on July 15, 2006. (Data from the MODIS instrument on the Terra satellite.)

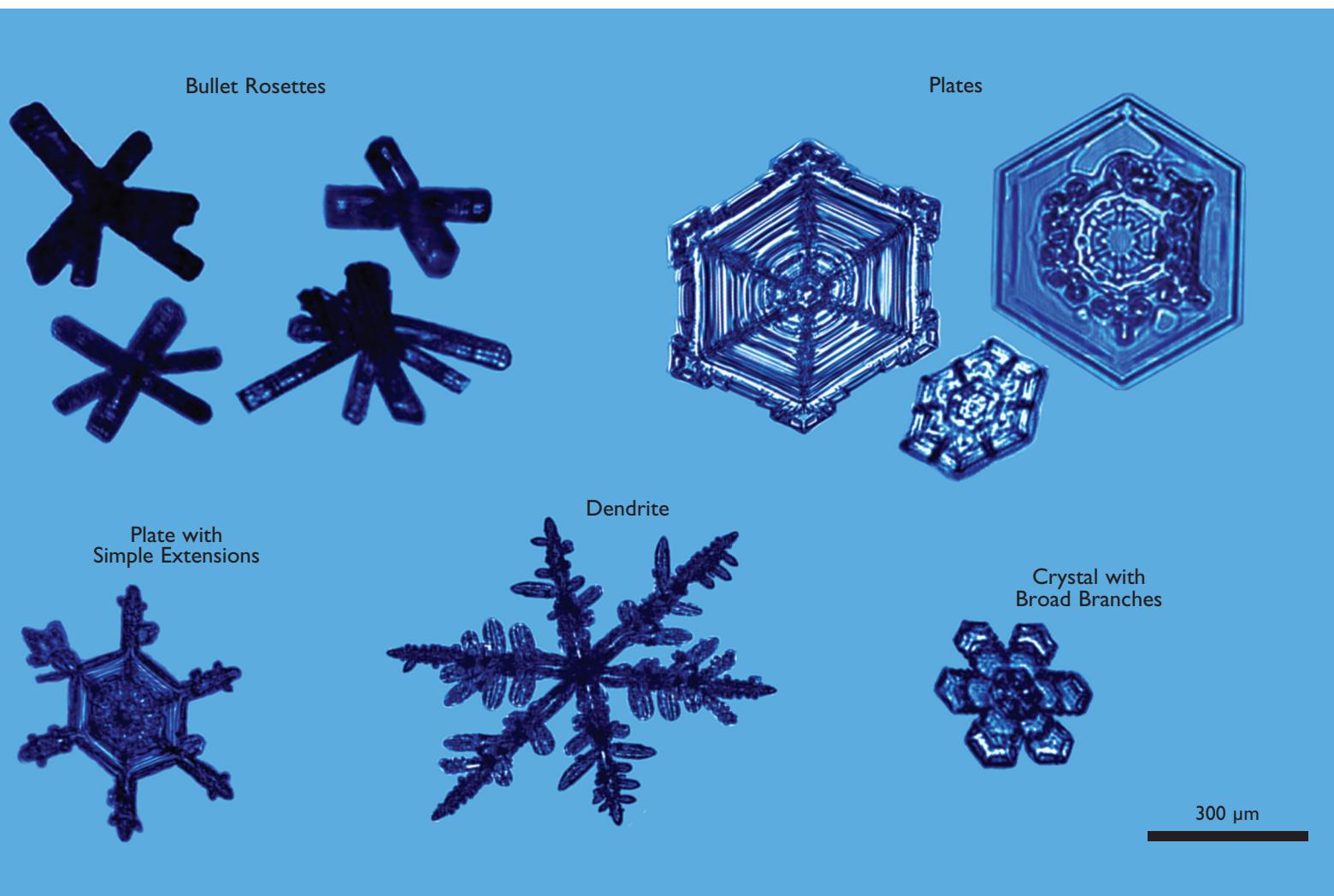


Global distribution of cloud fraction (top) and cloud effective radius (bottom) of ice clouds for July 2006. (Data from the MODIS instrument on the Terra satellite.) Inset: Deep convective clouds and thin ice clouds off the Philippines and Indonesia on July 14, 2006. (Data from the MODIS instrument on the Terra satellite.)



only be determined from global satellite observations, which provide us with a mechanism to determine the presence, spatial distribution, and frequency of occurrence of both liquid water and ice clouds.

Low-level clouds that occur at temperatures above 0°C, such as marine stratocumulus, altocumulus, and cumulus humilus clouds, are composed of liquid water droplets. Areas where these types of clouds dominate include oceanic regions off the west coasts of the United States, Peru, and Namibia, where they occur 60–90% of the time, depending on time of year. High-level clouds are often quite thin, such as cirrostratus and cirrus uncinus (*mare's tail* clouds), but can also occur as deep convective cumulonimbus clouds. These clouds are composed exclusively of ice particles, especially in the upper layers of the clouds. Thin ice clouds are readily observed in the Earth's atmosphere when they contribute to atmospheric optical phenomena such as sundogs or haloes, a clear indication of the presence of hexagonal ice crystals. Areas where these kinds of ice clouds dominate include the intertropical convergence zone and deep convective clouds in the tropics, such as over the Congo basin and the western tropical Pacific. These clouds are composed of complex ice crystal shapes such as columns, plates, bullet rosettes, dendrites, and aggregates like graupel or hail, and form at temperatures less than 0°C. Liquid water clouds can, and often do, form at temperatures below freezing, and are then referred to as supercooled clouds. At temperatures less than  $-39^{\circ}\text{C}$ , however, only ice crystals can exist in the Earth's atmosphere.



Using a complex process to determine the presence of clouds and their thermodynamic phase, one finds that clouds occur over all latitudes and over a wide range of altitude, but it is possible from space to determine the presence, height, and optical thickness (opacity) of clouds, as well as their phase and cloud drop (or ice crystal) size. What size droplets exist in water clouds around the world? It turns out that the effective radius (characteristic size) of cloud drops ranges largely between 7 and 10  $\mu\text{m}$  for low-level marine stratocumulus clouds to perhaps 20  $\mu\text{m}$  for cumulus humilis and cumulus congestus clouds over the tropical oceans. It is also readily observed from space that liquid water cloud droplets are larger for clouds over the ocean than over the land, due primarily to the fact that cloud drops form on particles in the Earth's atmosphere, as first noted by John Aitken, and there are more particles over land than over the ocean. With more particles to distribute water vapor around, clouds over the land tend to have more cloud drops but they are smaller in size. Ice clouds also show a preference for larger crystals over ocean than over land, but ice particles in clouds are typically between 20 and 35  $\mu\text{m}$  in effective radius, somewhat larger than water drops, but not in large numbers at precipitation size particles. Most clouds, whether they are liquid water or ice clouds, do not precipitate.

Digital images of ice crystals in clouds. A broad range of temperatures and humidities in clouds lead to the growth of different ice crystal shapes, which scatter light in widely different patterns. (Data from the CPI instrument on the SPEC Learjet, provided by Paul Lawson.)

The rugged terrain of the eastern Pacific island of Guadalupe reaches a maximum elevation of 1.3 km and disturbs the flow of air around the island, made visible in this June 11, 2000 image by the marine stratocumulus clouds that are below the altitude of the island peak. Turbulent atmospheric flow patterns known as von Karman vortex streets form in the wake of an obstacle. Guadalupe is a volcanic Mexican island located 260 km west of Baja California. (Data from the MISR instrument on the Terra satellite.)

